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SMALL SATELLITE MISSIONS

Background paper 9

The full list of the background papers:

1. The Earth and its environment in space
2. Disaster prediction, warning and mitigation
3. Management of Earth resources
4. Satellite navigation and location systems
5. Space communications and applications
6. Basic space science and microgravity research and their benefits
7. Commercial aspects of space exploration, including spin-off benefits
8. Information systems for research and applications
9. Small satellite missions
10. Education and training in space science and technology
11. Economic and societal benefits
12. Promotion of international cooperation

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PREFACE

The General Assembly, in its resolution 52/56, agreed that the Third United Nations Conference on the Exploration and Peaceful Uses of Outer Space (UNISPACE III) should be convened at the United Nations Office at Vienna from 19 to 30 July 1999 as a special session of the Committee on the Peaceful Uses of Outer Space, open to all Member States of the United Nations.

The primary objectives of UNISPACE III will be:

(a) To promote effective means of using space technology to assist in the solution of problems of regional or global significance;

(b) To strengthen the capabilities of Member States, in particular developing countries, to use the applications of space research for economic and cultural development.

Other objectives of UNISPACE III will be as follows:

(a) To provide developing countries with opportunities to define their needs for space applications for development purposes;

(b) To consider ways of expediting the use of space applications by Member States to promote sustainable development;

(c) To address the various issues related to education, training and technical assistance in space science and technology;

(d) To provide a valuable forum for a critical evaluation of space activities and to increase awareness among the general public regarding the benefits of space technology;

(e) To strengthen international cooperation in the development and use of space technology and applications.

As one of the preparatory activities for UNISPACE III, the Office for Outer Space Affairs of the Secretariat has prepared a number of background papers to provide Member States participating in the Conference, as well as in the regional preparatory meetings, with information on the latest status and trends in the use of space-related technologies. The papers have been prepared on the basis of input provided by international organizations, space agencies and experts from all over the world. A set of 12 complementary background papers have been published and should be read collectively.

Member States, international organizations and space industries planning to attend UNISPACE III should consider the contents of the paper, particularly in deciding on the composition of their delegation and in formulating contributions to the work of the Conference.

In the preparation of the present background paper, contributions from the following organizations have been used: Centre national d'études spatiales of France; Centre royal de télédétection spatiale of Morocco; European Space Agency; International Academy of Astronautics; Subcommittee on Small Satellites for Developing Nations; Korea Advanced Institute of Science and Technology; Surrey Satellite Technology Ltd., located at the University of Surrey, United Kingdom of Great Britain and Northern Ireland and World Meteorological Organization.

The assistance of M. J. Rycroft (International Space University, Strasbourg, France, and Cambridge University, United Kingdom) as technical editor of background papers 1 to 10 (A/CN.184/BP/1-10) is gratefully acknowledged.

SUMMARY

Small satellites offer valuable missions with current and emerging technologies, for all fields of science and applications, for technology demonstrations and for education and training. This is not only true in industrialized countries, which already have established space programmes, but it is also particularly important for developing countries and countries emerging in space technology, which can then have access to space missions, applications and spin-off technologies. Together with reduced development times, the inherent reduction of launch costs offered by the reduced size and mass of the spacecraft and their more manageable proportions, small satellites become attractive ways to develop and establish a national expertise in space technology and to serve the needs of all countries in accessing new missions.

Small satellites have considerably augmented the range of possible space missions, thereby lowering the cost threshold of access to space for countries emerging in space technology. Small satellites are not a solution for all types of mission, but offer the possibility of performing ambitious scientific experiments and applications as a complement to large missions. Their capabilities increase with improvements in electronic processors and sensors.

Small satellites can be developed through international cooperation, at either the regional or higher levels. Cooperative programmes also offer opportunities for engineers and scientists to be trained in satellite design, production and operations. Small satellite missions are particularly attractive for so-called "space-emerging" countries—which are countries with a technical knowledge base and some space experience, striving for small satellite missions to exploit the new, cost-effective possibilities they offer.

The philosophy and roles of microsatellites and small satellites are examined here, as are also the economic aspects of small satellite projects, the roles of educational and research institutions and of the commercial sector, and the possibilities for cooperation at the regional and international levels.

I. PHILOSOPHY OF SMALL SATELLITES

1. In the early days of space exploration, most space missions were small, primarily because the launch capability was small. As the launchers grew, so did the satellites. However, it must not be forgotten that an incredible increase in human knowledge came from those early small satellites. As projects, mainly scientific projects, grew larger, there was a general concern in the global space community about the gradual decrease of the number of flight opportunities for any particular discipline, the increasing costs of more and more complex missions and their decreased flexibility (because of long development times, for example).

2. The need to return to smaller missions was therefore initiated by the space community, which was then being consolidated by the reduction in space budgets. However, the return to small satellite missions was also driven by advancements of technology. Thus, small satellites could be developed that not only provided valuable scientific returns, but also allowed completely new applications in remote sensing, environmental monitoring and communications.

3. There is no universally accepted definition of a "small satellite". Usually, an upper limit of about 1,000 kilograms is adopted. Below that limit, satellites over 100 kilograms are frequently called "minisatellites", between 10 and 100 kilograms "microsatellites" and below 10 kilograms "nanosatellites". At the University of Surrey, United Kingdom of Great Britain and Northern Ireland, satellites having a mass between 500 and 1,000 kilograms are called "small" and between 100 and 500 kilograms "mini". The European Space Agency (ESA) usually considers 350-700 kilogram satellites "small", 80-350 kilogram "mini" and 50-80 kilogram "micro". The cost of developing and manufacturing a typical minisatellite is between US$ 5 million and 20 million, a microsatellite between US$ 2 million and 5 million and a nanosatellite could be below US$ 1 million. In the present paper, the generic term "small satellite" is used for a spacecraft of less than 1,000 kilograms.

4. The small space mission philosophy can be stated as essentially a design-to-cost approach, within strict cost and schedule constraints and with, as far as possible, a single mission objective. This philosophy is supported by the following four trends.

Electronics miniaturization and growth of performance

5. Improvements in electronics technology have resulted in many of the items used in our everyday life (from computers to video cameras, portable phones, radios and watches) becoming smaller, more efficient and generally cheaper. This is also true for all satellite equipment affected by electronics and software. Mass-market devices drive technological developments. Non-space-qualified processors and mass memories, more powerful than their space-qualified equivalents, have been successfully flown on small missions. Micro-machining technologies have enabled bulky electro-mechanical sensors, such as accelerometers, to be replaced by very low-mass, low-volume semiconductor sensors.

Appearance of small launchers

6. The mass of geostationary telecommunications satellites has grown because of the need for increased lifetime, power and number of channels. Launch vehicles have grown accordingly; added performance has enabled double launches of telecommunications satellites and has been needed to support manned missions. This capacity has driven up the size of scientific missions, with some benefits in terms of economies of scale, but the downside is the long time involved in securing funding for such large, costly missions and the complexities of coordinating the conflicting requirements of the various instruments. To counter that trend, in the late 1980s the United States of America supported the commercial development of new small launchers (operational in the mid-1990s). Commercial, generally smaller and cheaper, launchers are now also successfully used to create "constellations" of small communications satellites in low-Earth orbits. The Russian Federation has promoted the use of modified military missiles to launch small satellites and could have a major influence

on the small satellite market owing to the high reliability, large stockpile and low cost of such launchers. Europe, with its Ariane launcher, is playing a major role with a special platform devoted to microsatellite launches (see para. 50).

Independence

7. A small satellite carrying a single instrument and a dedicated launch is often the affordable way for emerging "space-faring" nations to put their own satellite into orbit. Small satellites also enable individual countries to obtain a completely independent communications, Earth observation or defence capability at a rather low cost, so that they are not totally reliant on major space-faring countries. Even if the performance of the small satellites cannot match the larger satellites in all aspects, they are under that nation's direct control and that is a very attractive feature.

Mission complexity and cost of multi-instrument satellites

8. The growth in cost and complexity of traditional scientific missions has caused a parallel growth in the constraints and the management layers associated with those missions. Increasingly stringent safety regulations have been introduced to protect the investment, preventing the use of state-of-the-art technologies. The end-users then had less control over the mission and considerably more time to wait for the results. Small mission platforms can flight-demonstrate and qualify new equipment, sensors and systems cheaply and deliver meaningful results in a short time.

9. In the 1990s there has thus been growing interest in returning to the use of small satellites, which can be launched a few years after programme initiation. That small mission philosophy was also adopted by the National Aeronautics and Space Administration (NASA) of the United States of America, with its "faster, better, cheaper" approach. Scientific missions for near-Earth and planetary explorations are now conducted in accordance with that philosophy: several spacecraft in the new generation have already been launched and successfully operated. Along with the reduced size of the mission, the customer oversight has also been reduced, leading to further cost reductions, although the level of quality of the product must still be maintained to assure mission success.

10. An excellent case history is the programme of the Institute of Space and Aeronautical Sciences (ISAS) of Japan, where most, if not all, of the scientific spacecraft have been of the small class, providing valuable scientific returns, and also in cometary and lunar exploration. The reduction in the size of the satellites is now evident in more focused Earth observation missions, with fewer smaller instruments providing full services to specific or national user communities along with the larger land remote-sensing (LANDSAT) satellites, the ESA's Envisat and Meteorological Operational (MetOp) or the Système pour l'observation de la Terre (SPOT)-type satellites.

11. Most of these new missions are driven by the worldwide reduction in space budgets, but they are also made possible by taking full advantage of technological developments—the miniaturization of engineering components and the development of micro-technologies for sensors and instruments for well-focused and small-scale scientific and Earth observation missions. At its extreme, the miniaturization process leads to the integration of microelectromechanical systems using microelectronics for data processing, signal conditioning, power conditioning and communications, that is, the concept of the application-specific integrated microinstrument. Initial evaluations of micro- and nano-technologies have even led to the concept of nanosatellites with dimensions of a few centimetres and masses of only a few kilograms, constructed by stacking wafer-sized application-specific integrated microinstruments together, with solar cells and antennas on the exterior surface.

12. Thus small spacecraft do not imply low technology and short lifetimes: on the contrary, they may mean very advanced technology, offering larger payload mass in relation to the total mass of the spacecraft. In fact,

the small satellites offer valuable missions, even with today's technology, for science and applications as well as for education and training. Together with reduced development times and the inherent reduction in launch costs offered by the reduced size and mass, the small satellite concept becomes an attractive solution to serving the needs of the new missions. This is particularly important for the developing countries, which can then afford to have access to space missions, applications and the relevant technologies.

II. COMPLEMENTARITY OF LARGE AND SMALL SATELLITE MISSIONS

13. Small satellite missions do not replace large satellite missions, as their goals and issues are often different. Small missions are complementary to larger missions. By developing new methodologies and techniques, small satellites can spearhead pioneering advances in experiments and technologies that are later flown on major missions.

14. Small satellites have several advantages over larger ones, for both large and small countries: more frequent and more varied mission opportunities; more rapid expansion of the technical knowledge base; greater involvement of local industry; and greater diversification of potential users.

15. Of course, one solution is not necessarily applicable to all problems. There are, for instance, good reasons why geostationary satellites are growing in mass: the number of positions available in geostationary orbit is limited and a longer lifetime increases the return on investment. In general, there is a similar relation between small and large satellites as between microprocessors and mainframe computers. Some problems are better addressed via distributed systems, for example, constellations of microsatellites or small satellites (typically for global coverage), while others may require centralized systems (e.g. a large optical instrument, as in a space telescope or a high-power direct-broadcast communications system).

16. Affordable small satellites require a very different approach to management as well as to technology, if cost, performance and delivery targets are to be met. Several attempts at using a traditional aerospace organization to produce such satellites have failed because of the rigidity of the management structure and conservative thinking. Small teams (25 persons), working in close proximity with good communications and well-informed and responsive management personnel, are essential. Such characteristics are best found in small companies or research teams, rather than in large aerospace organizations, which may find it difficult to adopt or modify the procedures necessary to produce affordable small satellites using staff and structures intended for large aerospace projects.

17. Specifically, a successful small satellite project requires:

(a) Highly innovative technical staff;

(b) Small, motivated teams;

(c) Personal responsibility, rigour and quality;

(d) Good team communications, close proximity;

(e) Well-defined mission objectives and constraints;

(f) Knowledgeable use of modern components;

(g) Layered, failure-resilient system architecture;

(h) Thorough testing of both components and the whole system;

(i) Technically competent project management;

(j) Short timescale (to prevent possible escalation of objectives).

III. SCOPE OF SMALL SATELLITE APPLICATIONS

18. Social and economic problems may be addressed by various applications of space technology, in particular those using small satellites. Such direct needs can be classified by geographical location, by type of services and products or by type of applications. Today it is usual to focus on problems such as communications or monitoring of remote areas, agricultural land use and environmental protection. In addition to those direct needs, it is also important to realize th t small satellites can be the best way to test and validate new technology. Finally, the subject of academic tr ning requires specific attention, as small satellites can play a significant role there, especially for developing countries.

A. Telecommunications

19. The subject of telecommunications has many space applications. For the purpose of the present paper, discussion will be restricted to remote and mobile communications (including messaging, electronic mail and localization) using small satellites in low-Earth orbits.

20. The use of low-Earth orbit communications systems allows many services, such as communications between a portable terminal, similar to that employed in cellular telephone communications, and a normal telephone of the existing fixed telecommunications network. In that case, the two users may be located anywhere in the territory, so that this is especially attractive in remote areas or in regions lacking communications infrastructures. On the other hand, communications are also feasible between a mobile user and a user of the fixed network system anywhere in the world. In that case, the final connection is completed through the existing network system.

21. The use of automatic data-collection platforms, in conjunction with the two-way characteristics of low-Earth orbit communications, allows the installation of a data-collection network that features a wide coverage and provides real-time service. In addition, the low-Earth orbit communications system can give the location of any user of a mobile terminal. The location accuracy, in the hundred-metre range, is adequate for most applications. The low-Earth orbit communications mobile terminal can also be coupled to a facsimile machine for the transmission of graphical data. Thus it will be possible, for instance, to send a facsimile of an electrocardiogram in the case of a medical emergency in a remote area.

22. Telemedicine is an application that will increase the efficiency of medical services by allowing the transmission of information obtained by cheap and simple sensors directly to complex processing units in large medical centres where it can be properly interpreted by specialized physicians. Thus, powerful and effective emergency services can reach poor and undeveloped areas, saving many lives and avoiding the unnecessary displacement of patients. The HealthNet project is a very good example of a telemedicine application: it uses a 60-kilogram microsatellite (HealthSat) in low-Earth orbit to relay medical data and information between a number of African countries and North America.

23. To increase the immunity to failure under disaster conditions, mobile communications may also play an important role in the case of a large natural disaster: help should reach the disaster victims faster than otherwise and the mobile communications provide logistic support to the rescue teams.

24. Low-Earth orbit communications could be the solution to communications problems for large remote areas in developing countries. It is necessary to concentrate efforts in that direction, while the currently proposed low-Earth orbit communications systems are oriented towards the large, sophisticated market in developed countries.

The cost to end-users can become unrealistic for remote areas in developing countries, which is why they should make a significant effort to define their needs properly. This will then help the process of international coordination and regulation of the radio frequency spectrum. By their very nature, such missions become an important factor in bringing the benefits of education and social development to all people.

25. An example of such a dedicated mission for developing countries is the ECO-8 project, which was originally conceived by Brazil. Considering that most of that country is in the tropical zone, Brazil specialists realized that low-inclination orbits would be appropriate to cover their needs. This means that instead of a large number of satellites such as in the Iridium (66) or Globalstar (48) programmes, only 8 (or possibly 12) satellites could provide the service. Such a much cheaper system could also interest other tropical countries.

B. Earth observations (remote sensing)

26. The Earth observation applications considered here cover the various aspects related to data collection and imagery. As for telecommunications, Earth observation may be examined from different points of view. With the special features of each country, different unique scenarios of applications can be identified. In any case, low-cost small satellites can now make affordable multi-satellite networks of Earth observation satellites to reduce observation intervals from 10 to 20 days to around 12 hours, anywhere on the Earth's surface.

27. Many countries have had early access to the benefits of satellite remote sensing, but still have a long way to go in order to maximize the benefits allowed by their existing capabilities. There are, however, unique needs at both the national and regional levels that demand new solutions. Brazil and the Republic of Korea, for instance, are already developing new satellite programmes to address their specific needs. Latin America, South-East Asia and other developing areas require special capabilities related to sensor parameters, such as specific spectral bands, spatial resolution, time resolution, cost of image, autonomy and investment level in ground equipment, and the expertise required for their utilization.

28. During the United Nations Conference on Environment and Development, held at Rio de Janeiro from 3 to 14 June 1992, sustained development and biodiversification were terms mentioned and defended in every speech made by the Heads of State. Careful and sustained development can only happen with provision for local monitoring and control of the use of natural resources. By obtaining regular, global and permanent information on its resources, as can, for example, be provided by small dedicated satellite, a country can plan its policy for the longer term. Remote observations from satellites and distribution of the remote-sensing data should thus help to slow the depletion of natural resources, including the rain forest. It is also important in sustained development that the logistics necessary to support settlement and employment be considered.

29. Remote sensing, with portable ground stations and low-cost space systems, has an important role to play here. A key feature of the space system is direct down-linking to numerous small ground stations, eliminating the need for a centralized processing and distribution system. The advantages are real-time access to observations, smaller databases and ease of information distribution, even in areas not well served by communications systems. In some cases—forest and brush fires, pollution, fishing and storms—monitoring in real time and decentralization are a sine qua non. In the area of disaster prevention, there are clear demands for earthquake forecasts, early detection of tropical storms and anticipation of volcanic activity. Scientific and system design activities should be carried out in those areas.

30. The present constellations of polar-orbiting and geostationary meteorological satellites allow for the sharing of common costs and for synergy between sensors (simultaneous data on a given area). The advancements in sensor technologies, in particular new types of active and passive microwave detectors, open up possibilities to consider small satellites with a specific payload and mission. In the near future, small satellite missions may be flown with only one instrument. There are many advantages for such a constellation, for instance, the decrease in vulnerability by moving away from a single point of failure.

31. Another philosophy being proposed by some private organizations is commercialization, whereby the private sector would assume the role of building, launching and operating environmental monitoring satellites. Scientific data obtained in that way could then be purchased by organizations, such as national meteorological and hydrological services.

C. Scientific research

32. One of the main advantages of small satellite scientific projects is the possibility to perform simultaneous measurements of physical parameters from different locations in space. The concept of a large (mother) satellite and a small (daughter) subsatellite has been used successfully to separate the time and space components of variations of geophysical parameters in the framework of the international projects Aktivny, Apex and Interball. The Czech-made Magion subsatellites of about 50 kilogram mass were able, from a controlled distance, to complement the data gathered from the mother satellite. There are many ongoing cooperative scientific programmes in the area of solar and space plasma physics which illustrate this advantage of small satellites to offer support in taking multi-point measurements of various phenomena, in particular in the International Solar-Terrestrial Physics programme, involving the Solar and Heliospheric Observatory (SOHO) of ESA, Wind and Polar (NASA), Geotail (ISAS) and the future Cluster 2 (ESA). Of course, not all parts of the project are small satellites (e.g. SOHO).

33. Examples of small scientific satellites from developing countries are FASat (Chile) for monitoring ozone depletion and the KITSAT project of the Republic of Korea, which uses an instrument for monitoring geomagnetically trapped particles.

34. During the last decade there has been considerable progress in understanding the global behaviour of upper atmospheric regions and their relationship with the interplanetary medium. Such studies have been heavily concentrated in the northern hemisphere of the Earth's globe, however. It seems highly advisable, therefore, that developing countries, which are located in many cases in the southern hemisphere—and in particular in the tropical zone—should join the global effort towards improving the knowledge of their own space environment. It does not make sense that such important environmental studies, which are for the benefit of all humanity, should be restricted to the Earth's northern hemisphere. The countries of the southern hemisphere certainly have the necessary human resources, skills and motivation to carry out such studies.

35. As a consequence of the relative lack of space science studies in the southern hemisphere, several natural phenomena that occur in the upper atmosphere in the tropical and southern hemisphere zone are not adequately understood. Examples are ionospheric plasma depletions, or bubbles, which occur over the South American sector and strongly affect radio communications as nowhere else in the low latitudinal region of the globe, or the South Atlantic geomagnetic anomaly, with its large fluxes of precipitating energy-charged particles from the inner Van Allen radiation belt, causing severe physical damage or even the complete destruction of satellite instrumentation (such as sensors, solar cells or photometric devices).

36. The southern hemisphere is also an important region for studies in the field of astrophysics, especially for studies of regions of the sky not directly accessible from the northern hemisphere; many developing countries located in the southern hemisphere have been engaged in astrophysical studies over the past few decades. Satellites would be an important means of complementing the ground-based studies that have been carried out so far by developing countries and a course for future studies.

37. Recent examples of small planetary missions are the highly innovative and successful Discovery and New Millennium programmes in the United States, the planetary and lunar missions developed by ISAS in Japan and the University of Surrey's low-cost lunar mini-satellite proposal. They show the very high benefits of such new approaches, which fall into the category of "faster, better, cheaper" programmes.

D. Technology demonstrations

38. The demonstration of technology is an obvious application for small satellites, which are an attractive and low-cost means of demonstrating, verifying and evaluating new technologies or services in a realistic orbital environment and within acceptable risks prior to commitment to a more expensive, full-scale mission. Examples have been NASA's Discovery and New Millennium programmes, the Japanese Hypersat class and ESA's Project for On-Board Autonomy (PROBA). The Centre national d'études spatiales (CNES) in France is developing a universal platform, Proteus, aimed at various applications in space research, remote sensing and telecommunications, but also usable for technology demonstrations. CNES is also developing a microsatellite (100 kilogram) family for technology, science and application missions.

39. The NASA Discovery programme is a typical example of missions designed to demonstrate technology for solar system exploration (Lunar Prospector, Mars Pathfinder, NEAR). While this programme is known because of the type of mission and the media coverage, other missions have been flown with success, leading to a collection of valuable data on material and equipment behaviour in the space environment, especially in the hazardous radiation environment in low-Earth orbit or even in the geostationary transfer orbit. Examples are the space technology and research vehicle satellites of the United Kingdom.

E. Academic training

40. The growing space industry and the many associated service and scientific organizations require a steady flow of enthusiastic, trained and competent young engineers and scientists to meet the challenges of the future. Indeed, countries emerging in space technology who wish to take their first steps into space also need to learn from more experienced space users and to generate a cadre of trained personnel before establishing their own national agencies and presence in space. Very successful small satellite technology transfer and training programmes have been completed between the United Kingdom and Chile, Malaysia, Pakistan, Portugal, the Republic of Korea, South Africa and Thailand.

41. Although small satellites are physically small, they are nevertheless complex vehicles that exhibit virtually all the characteristics of a large satellite. This makes them particularly suitable as a focus for the education and training of scientists and engineers by providing a means of direct, hands-on experience at all stages and in all aspects (both technical and managerial) of a real satellite mission—from design, production, test and launch through to orbital operation. Education in space technology is a most important item in many parts of the world.

42. Universities and schools of engineering in several countries have already developed, launched and operated their own small satellites: this has been the case in several countries in Europe. Others are currently engaged in the same process, for instance, Japan, where it has taken the form of a contest between students, South Africa and the United States (NASA's Office of Space University Explorer (UNIX) mission programme). A university environment is an ideal place for inaugurating space activities. Thus the usual spin-off of a space programme, that is, the acquisition of technology and the development of an industrial organization and management methods, will begin to accumulate at the national level as the students leave the university and start their professional lives.

43. The advantage of low cost, rapid timescale and manageable proportions makes this approach very attractive to countries wishing to develop and establish a national expertise in space technology. They can be either purely national programmes, but most generally they are cooperative programmes with a technology transfer content. They typically have the following content—academic education, on-the-job training and cooperation on the satellite and the ground station, and support for satellite operation.

IV. POSSIBILITIES OF LOW-COST LAUNCHINGS OF SMALL SATELLITES

44. The low-cost access to space is a critical enabling capability, in particular for developing countries with limited resources to expand their initial space activities. Launch opportunities for small satellites include launch on a dedicated expendable launch vehicle; launch as a secondary, or "piggyback", satellite on a large expendable launch vehicle; launch as one of two spacecraft launched on a dual mission on a single expendable launch vehicle; and launch carried in one of the small satellites services offered by the Space Shuttle (the so-called "get away specials" payload bay slots).

45. The choice of one of these involves an assessment of the unique mission requirements against the capabilities, costs and constraints of the launch options. The most important considerations are flexibility as regards date of launch and orbit (in the case of a shared launch) and the value of the spacecraft. A second consideration should be the reliability record or flight history of the potential launch vehicle. Those launching a series of low-cost payloads may be willing to take the risk of a new lower-cost launch vehicle with an unproven record. Once a commitment is made to a particular vehicle, the spacecraft with its payload may require some modifications if it is to be launched on a vehicle different from that for which it was originally designed.

A. Dedicated launches

46. During the past 30 years, many countries have invested in the development of an indigenous launch vehicle capability, pursuing the lucrative commercial market or strengthening their own civil and national defence programmes. International space policies and programmes are emerging with commercial developments and advances in related technologies. The small class of expendable launch vehicles has experienced the largest entry of commercial entrepreneurial activity, both in the United States and abroad over the past few years (including airborne launchers like Pegasus). Also, the long-range and intercontinental missiles from military arsenals of the cold war rival super-Powers are now available for civilian space launches.

47. The specific cost per kilogram into orbit of small launchers is higher than that of larger launch vehicles, but their absolute cost is much lower. Some operators also offer lower prices for their launching services, especially on newly introduced launchers (the ride on a test flight might even be free of charge). Small-class expendable launch vehicles can deliver payloads weighing from as little as 25 kilograms to as much as 1,500 kilograms to low-Earth orbit. Launching two or more small satellites on the same expendable launch vehicle ("dual manifesting") is a viable alternative (see para. 50).

B. Secondary/piggyback launches

48. In an effort to reduce the cost of access to space and to make use of surplus performance capabilities, larger expendable launch vehicle manufacturers are interested in offering the small payload community the option of flying as a secondary, or "piggyback", payload on those missions where the primary payload does not fully utilize the vehicle capability. Such possibilities have been used during some United States Delta launchings and Russian Federation Soyuz and Tsiklon launchers associated with main payloads of the Resurs and Meteor satellites. The primary payload schedule and reliability remain unaffected by the companion payload and the small payload owner is provided with a potentially cost-effective alternative to the purchase of a dedicated small expendable launch vehicle.

49. However, piggyback launch opportunities in low-Earth orbit are relatively rare and the mission parameters and schedule are dictated by the main user. It may be expected that the multiple launches into low- and medium-Earth orbits required by the new telecommunication constellations may provide more opportunities for piggyback launches in the future.

50. For the European Ariane 4 launcher, a special supporting structure, the Ariane Structure for Auxiliary Payloads (ASAP), has been developed to launch several small satellites simultaneously. The mass of an individual satellite (up to seven per launch) is limited to 50 kilograms, while the new more powerful Ariane 5 launcher provides for several 50-100 kilogram satellites. This greatly facilitates launchings of small piggyback satellites into geostationary transfer orbits or, in some cases, into low polar orbits.

C. Ways to obtain launch access

51. There are several ways to obtain launch access, either on a purely commercial basis or through participation in international cooperative agreements. A country may also consider developing its own launch capability. A driving force in pursuing this approach is the lack of available low-cost launchers and an inability for the country to meet its launch requirements on a timely basis (if it views access to space as critical to its national development).

52. The acquisition of launch services from international commercial sources is sometimes preferable to cooperative arrangements, owing to difficulties in finding an appropriate exchange of opportunity. In particular, a country seeking its first launch may find commercial acquisition the most effective route open to it. Such launch services should be planned as an integral part of the country's long-term planning of its space programme. A country newly embarked on satellite activities and seeking to develop a national infrastructure (governmental and/or industrial) must also establish priorities for the development of expertise in managing launch activities.

53. Cooperative missions may be considered when a clear programmatic benefit is shared by more than one country with a mutual desire to maximize their unique national resources and available funding. International cooperative agreements vary from mission to mission and from country to country; most require each country to assume full financial and technical responsibilities for its portion of the cooperative effort. In addition, clear and distinct managerial and technical interfaces are described in the agreements.

V. GROUND SUPPORT NEEDED FOR SMALL SATELLITES

54. The ground segment fulfils three functions: (a) the operations, which include the status and health monitoring of the satellite, and the command preparation and validation; (b) the tracking, telemetry and command functions, which are ensured by the communications station, possibly combined with the operations centre; and (c) the reception and transmission of the mission data to the user(s) for processing and further distribution.

55. Depending on the type of mission, the ground station for small satellites can be based on a simple very high frequency (VHF) antenna, as is the case with many standard platforms, such as the University of Surrey satellite (UoSAT) series in the United Kingdom, or it could be more complex, as required, for example, by an Earth observation mission. The reason is that the latter typically require acquisition of a large volume of data. Small satellites tend to rely more on on-board autonomy and safe modes. This reduces the need for continuous monitoring from the ground, thereby simplifying and reducing the cost of the ground segment. Recent availability of on-board navigational autonomy (using the global positioning navigational system) is encouraging that tendency.

56. The cost of mission operations represents a major part of the programme cost and it is important to find ways to minimize it. Reuse of the major agency tracking networks should be avoided for routine operations, although they may be required for the launch and early operation phase. It has usually proved far more cost-effective to employ national facilities, ideally utilizing a single ground station when feasible.

57. In order to reduce the cost of operations, it must be understood that a prime cost is human resources. The high reliability of the computers and the power of modern personal computers make autonomy an affordable solution. Many items in the operations scenario may be candidates for automation: antenna tracking, pass set-up and close-down, data reception and storage, conversion of raw data, status checking and so on. In the future, it may be possible for small satellites with reduced telemetry and availability requirements to use the mobile communications constellations as a global data relay system.

58. Although a ground system for a small satellite programme should have the lowest cost possible, it should still be reliable so as not to miss satellite passes or data. It should also offer a fast return of critical data together with a rapid response for critical commanding. For bulk data a regular return could be adequate, depending on the application. However, direct down-linking to user terminals and portable ground stations may be considered beneficial, especially for remote-sensing data, as already indicated.

VI. ECONOMIC BENEFITS OF SMALL SATELLITES

59. Usually, two different types of benefits are considered, depending on whether they are a direct result of the field of application or the result of the development of space system development in the country.

A. Direct benefits

60. Direct benefits from the use of small satellites may be identified, depending on their field of application. However, it must be understood that those benefits result from the application, which could also be provided by larger spacecraft. Small satellites provide their own contribution in such areas as:

(a) Improvement of agricultural and animal productivity in medium- to large-size farms owing to better weather predictions, identification of soil characteristics, improvements in communications and transportation;

(b) Lowering of transportation costs, made possible through the optimization of truck, bus and ship routing, location and early robbery detection, with favourable impact on the price of goods;

(c) Provision of communications for the basic needs of small rural settlements in remote areas;

(d) Improvements in natural disaster detection and relief, made possible by systems that integrate scientific, communications and remote-sensing satellite networks;

(e) Educational programmes for populations of remote areas.

B. Indirect benefits

61. The indirect benefits are particularly relevant to developing countries or to smaller countries that want to initiate a space programme. Space systems are indeed expensive, in particular from the standpoint of a developing country. However, international experience has shown that investments in the space sector have a very high multiplier effect on the gross national product: a factor around seven has been suggested in the literature.

62. It may be highly desirable for a country to maintain within its borders growing portions of the investments in commercial space systems and services. This can be achieved through increasing the participation of national industry in the international contracts for the provision of systems and services. This is not only a matter of governmental policy but also of the existing local capabilities.

63. Projects to develop small and microsatellite systems, because of their reasonable costs and shorter duration, can be the best strategy towards acquiring the expertise that is considered necessary to bring parts of governmental investments in commercial space systems and services into national operation.

64. Too often in the past, the lack of appropriate knowledge and training have resulted in decisions that have not best suited the needs of a country. Education programmes and formal training are necessary steps to acquire the desired capability, which should be negotiated as part of a contract to acquire space systems; this has, for instance, been the case in the development of the Koreasat telecommunications satellite programme. Such formal training is put to good use by working directly on space projects and, as noted earlier, small or microsatellite programmes may prove to be an affordable initial step for developing countries.

65. A coordinated interchange of information among countries in the same region of the world might be a proper way to increase expertise in defining the precise objectives of space programmes. In-depth studies to evaluate the actual needs can increase the chances that every country will choose the best alternative to suit its unique and changing needs, including through cooperative agreements with neighbouring countries.

66. The deployment of mobile telecommunication constellations will further benefit small missions. The production in series of small satellites for constellations is dramatically lowering the cost of off-the-shelf satellite equipment.

VII. INTERNATIONAL COOPERATION AT THE REGIONAL AND HIGHER LEVELS

67. According to those tenets established by the Charter of the United Nations and other agreements concerning international cooperation for the exploration and peaceful uses of outer space, each country has the right to have the opportunity to participate in space activities. In addition, each country has the obligation to cooperate in those efforts and to share existing information and adequate technology in order to help others to plan, develop, launch and operate satellites.

68. Although cooperative space activities have existed for a number of years, in particular as specific scientific endeavours, they are only now beginning to include small satellites. It is therefore highly desirable to define opportunities to widen the scope of cooperative efforts so that more countries have access to space and the resultant benefits to be derived from space technology. The small satellite option is undoubtedly the best opportunity available for developing countries to initiate their own space programmes in the most cost-effective way.

69. Examples of such programmes where engineers are trained on small satellite design, production and operations are numerous. Companies in the United Kingdom have for instance provided assistance to Chile, Pakistan and the Republic of Korea in the development of small satellites of less than 100 kilograms and even to small countries in Europe that had decided to initiate a space programme. Some countries, like the Republic of Korea, have initiated more ambitious programmes using small Earth-observation satellites of several hundred kilograms with the support of industrialized countries. The Technical University of Berlin is providing the Tubsat-C platform for a Moroccan project to build the first experimental national microsatellite for messaging and remote sensing. More classical cooperative programmes for the development of small satellites also exist, for instance between Argentina and NASA, or between Argentina and Brazil on a more regional basis. Other countries are already contemplating similar arrangements in order to develop a national space programme.

70. Cooperative space activities are often supported by some kind of technology transfer. A successful technology transfer in the development of small satellite activities implies a process by which a team acquires sufficient momentum to be able to produce the next generation of a small satellite. There are several mechanisms whereby technology transfer can be achieved, but, to be successful, the transfer should be a transfer of understanding, not the transfer of a technology package ("know-why" as well as "know-how").

71. Considering that all technology transfer processes typically involve people from different countries, it is necessary to meet some minimum conditions for successful implementation:

(a) Successful technology transfer can only be made to persons of sufficient technical and scientific background;

(b) Access to appropriate infrastructure to support the application of the technology should be available;

(c) A long-term development plan with scheduled objectives and proper financing should be in place, in particular because technology transfer is a long-term process.

72. Cooperative programmes, with some kind of technology transfer, when undertaken in an appropriate manner, are achievable and provide the key to accelerating access to space for those countries which elect to implement such a programme.

73. In the Asia and Pacific region in particular, there is no previous experience in cooperation in space fields and a wide range of economic and technological diversity. It is therefore very difficult for developing countries even to join an existing cooperative space project when some financial contribution is involved. In order to ease the situation, a framework has been proposed by the Economic and Social Commission for Asia and the Pacific (ESCAP), which has been subsequently acknowledged by member countries as a very feasible and appropriate approach at least at the Asia and Pacific regional level. Its modus operandi is based on the principle of percentage contribution, with participating countries sharing project expenses flexibly, based on their level of participation.

74. According to ESCAP, the technology required in pursuit of a project can be divided into two categories: published technology and new technology. When published technologies are involved, they can be used freely for the project (no technology transfer fee is involved). When new technologies are to be developed for a project, the cost for research and development activities should be covered by the project. Participation can take place on four levels:

(a) Host-level participation is for countries that have the technologies to build common payloads and are willing to offer such technologies for the project, without making a financial contribution to it. However, host-level countries should not charge for the use of their technologies within the project;

(b) Owner-level participation is for countries that will put common payloads on their own satellites and operate them, covering all the necessary expenses for manufacturing such payloads of their own. If new technology is required, the owner-level country should cover expenses for the necessary research and development activities;

(c) Partner-level participation is for countries that participate in manufacturing all or part of common payloads. Once common payloads are in orbit, host-level, owner-level and partner-level countries can use the constellation of satellites freely, based upon prior arrangements;

(d) The analysis work-level is for countries that do not participate in manufacturing common payloads but perform analysis and research using data gathered from the common payloads; access to data and other related information is guaranteed free of charge. If specific hardware or software is required, it should be developed at the expense of each participating country.

75. Expenses involved in attending meetings and seminars for the project should be covered by each participating country. When host or owner countries need to provide training for manpower from participating countries, this could be done at marginal cost and covered by the participating countries.

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EDUCATION AND TRAINING IN SPACE SCIENCE AND TECHNOLOGY

Background paper 10

The full list of the background papers:

1. The Earth and its environment in space
2. Disaster prediction, warning and mitigation
3. Management of Earth resources
4. Satellite navigation and location systems
5. Space communications and applications
6. Basic space science and microgravity research and their benefits
7. Commercial aspects of space exploration, including spin-off benefits
8. Information systems for research and applications
9. Small satellite missions
10. Education and training in space science and technology
11. Economic and societal benefits
12. Promotion of international cooperation

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PREFACE

The General Assembly, in its resolution 52/56, agreed that the Third United Nations Conference on the Exploration and Peaceful Uses of Outer Space (UNISPACE III) should be convened at the United Nations Office at Vienna from 19 to 30 July 1999 as a special session of the Committee on the Peaceful Uses of Outer Space, open to all Member States of the United Nations.

The primary objectives of UNISPACE III will be:

(a) To promote effective means of using space technology to assist in the solution of problems of regional or global significance;

(b) To strengthen the capabilities of Member States, in particular developing countries, to use the applications of space research for economic and cultural development.

Other objectives of UNISPACE III will be as follows:

(a) To provide developing countries with opportunities to define their needs for space applications for development purposes;

(b) To consider ways of expediting the use of space applications by Member States to promote sustainable development;

(c) To address the various issues related to education, training and technical assistance in space science and technology;

(d) To provide a valuable forum for a critical evaluation of space activities and to increase awareness among the general public regarding the benefits of space technology;

(e) To strengthen international cooperation in the development and use of space technology and applications.

As one of the preparatory activities for UNISPACE III, the Office for Outer Space Affairs of the Secretariat has prepared a number of background papers to provide Member States participating in the Conference, as well as in the regional preparatory conferences, with information on the latest status and trends in the use of space-related technologies. The papers have been prepared on the basis of input provided by international organizations, space agencies and experts from all over the world. A set of 12 complementary background papers have been published and should be read collectively.

Member States, international organizations and space industries planning to attend UNISPACE III should consider the contents of the present paper, particularly in deciding on the composition of their delegation and in formulating contributions to the work of the Conference.

The present paper was prepared with the assistance of teams of experts from the United Nations Office at Vienna, the World Meteorological Organization, the Centre for Space Science and Technology Education in Asia and the Pacific (India), the Centre national d'études spatiales (CNES) of France, the Centre royal de télédétection spatiale of Morocco, the European Space Agency (ESA), the Harvard-Smithsonian Center for Astrophysics (United States of America), the Indian Space Research Organization (ISRO), the International Space University (ISU), the International Space Services (United States), the National Aeronautics and Space Administration (NASA) of the United States, the National Autonomous University of Mexico, the Brazilian National Space Research Institute, the Obafemi Awolowo University (Nigeria), the South African Astronomical Observatory and the University of London Observatory of the United Kingdom of Great Britain and Northern Ireland.

The assistance of M. J. Rycroft (International Space University, Strasbourg, France, and Cambridge University, United Kingdom) as technical editor of background papers 1-10 (A/CONF.184/BP/1-10) is gratefully acknowledged.

SUMMARY

Space science and technology education can be pursued at the elementary, secondary and tertiary levels. In the spacefaring States, elements of space science and technology have been introduced into the science curricula at those levels. Such an innovation has not taken place in many developing countries, partly because the benefits of space science and technology have not been appreciated enough, and partly because the facilities and resources for teaching science and technology at the educational institutions in those countries are not well developed.

Education and training in space science and technology in industrialized countries have become highly interactive. In those countries, the Internet and other information technologies have become useful tools in education and training programmes at all levels. International cooperation in the areas of education and training could be encouraged to enable developing countries to develop their own education and training programmes.

The infusion of elements of space science and technology into school science curricula at all levels could serve a dual purpose for industrialized and developing countries. It could revitalize the educational system, introduce the concept of high technology in a non-esoteric fashion, and help create national capacities in science and technology in general. Moreover, all countries can take advantage of the benefits inherent in the new technologies which, in many cases, are spin-offs from space science and technology.

There are challenges in the teaching of science, both in developing and industrialized countries, but the challenges are of a higher magnitude in developing countries. The general problem confronting science education is an inability of students to see or experience phenomena being taught, which often leads to the inability to learn basic principles and to see the relationship between two or more concepts and their practical relevance to problems in real life. Added to those problems are a lack of skills in the relevant aspects of mathematics and a lack of skills related to problem-solving strategies. There are also language problems, which are more acute in some developing countries where science is often taught in a language different from the mother tongue. Over the years, industrialized countries have overcome most of the basic problems, except perhaps the psychological problems that students have about science being a difficult subject. In developing countries, however, the basic problems still linger, exacerbated by the fact that there are very few academically and professionally well-trained teachers.

Extension and outreach programmes are essential components of education and training in space science and technology. Communications skills must be developed and learned to convey scientific and technological concepts, thoughts, observations and practical results to the non-scientific communities.

Education and training in space science and technology are integral programmes of the missions of many space organizations both in industrialized and developing countries. Such educational programmes exist in the Centre national d'études spatiales (CNES) (French National Centre for Space Studies), the European Space Agency (ESA), the Indian Space Research Organization (ISRO), the Instituto Nacional de Pesquisas Espaciais (INPE) (Brazilian National Space Research Institute), the National Aeronautics and Space Administration (NASA) (United States of America), and the National Space Development Agency (NASDA) (Japan), to name a few space agencies. Each space agency has a unique mission, generally not performed by any other organizational entity within the country concerned. For the purpose of the present background paper, educational programmes in space science and technology are illustrated by reference to the educational elements within NASA.

INTRODUCTION

1. An effective system of education is essential for all countries. Within the system, training programmes develop specific skills. If a country is to use space science and technology effectively, it must have policy makers, decision makers, and administrators capable of assessing the political, social and economic implications of science and technology, scientists capable of developing and adapting the technology, engineers to design applications systems, technicians to construct and operate the systems and teachers to teach science and technology. A variety of education and training programmes will be required at various levels and with various orientations or specializations.

2. It is important to make a distinction between the terms education and training. The objectives of education are to bring the individual to an understanding of a subject, so that he or she may form independent opinions, establish priorities and understand and discuss the methodology, the techniques used and their applications. Education is concerned with the development of mental ability and of mental power, and thus with the attitude of people. The objectives of training are to teach individuals to carry out specific tasks based on an accepted methodology and for which known techniques are available. Understanding of the context is not always required; often only the ability to apply the technique is needed. Knowledge of the subject as a whole may not be necessary. Training brings the individual to a desired standard of efficiency. This is achieved by instruction and practice.

3. The specific requirements for education and training depend on the specific field of science and technology. Operational satellite systems in communications and meteorology require engineers and technicians with well-defined skills; experimental systems in remote sensing require a more flexible approach. The field of communications, with its large industrial infrastructure, may adopt satellite technology more easily than the fields of meteorology or remote sensing with their smaller infrastructure. The end-users of the satellite technology may not be aware of the satellite, as is usually the case in communications. They may receive interpreted data from meteorological satellites, or they may receive raw data from remote sensing satellites. In communications, therefore, only those directly involved with the satellite may need to be trained. In remote sensing, a very wide range of people must be trained in various aspects of the new technology.

4. National policies on education and training in space science and technology could be part of an overall educational policy. Education should be regarded as a productive investment in human resources, resulting in personal growth and development, improved social satisfaction, higher efficiency and better public services. Education and training are the indispensable complements of any investment in new technology and in expanded public services, and such investments are prime catalysts in socio-economic development. The cross-section of society requiring education or training includes:

(a) Decision makers and planners, including politicians and senior officials, who should have a general awareness of space science and technology and its practical and policy aspects;

(b) Managerial people in institutions, agencies and private enterprises, who should have a sufficient scientific and technical background to coordinate activities regarding specific applications of satellite data and to establish facilities concerned with space science and technology;

(c) Personnel carrying out satellite surveying tasks at various levels, who should receive instructions for the interpretation of imagery and digital data for mapping and monitoring in various disciplines and environments;

(d) Technical support staff, from engineers to technicians, who should be responsible for construction, operation and maintenance of facilities and equipment, and who need manuals giving instructions for performing technical tasks;

(e) Research workers, who should develop interdisciplinary approaches in their work, and who possess in-depth knowledge of several aspects of space science and technology;

(f) Teachers, responsible for the education and training of the various groups of personnel, who should have insight in scientific and technical matters and experience in educational technology and curriculum development.

5. Industrialized countries that have consolidated organizations and infrastructures need training for specific skills and education for further development, improvement or transformation of existing infrastructure. Many developing countries are still at stages of institutional development in which a relatively large number of personnel, at various levels and in different categories, are to be trained in specific skills in a short period of time. In addition, education is required to establish or modify professional infrastructures. Marked differences in the level of socio-economic and institutional development occur between regions and countries. That is reflected in the number of personnel needed for the various categories, and in the levels at which education and training is required. It is also reflected in the degree of dependence on outside education or training facilities.

6. In 1997, Mars Pathfinder began a 10-year programme of robotic exploration of Mars as hundreds of millions of people throughout the world follow the exploits of Sojourner on the surface. Daring spacewalks outside Mir have made this ageing space station once again a working laboratory. The first spacewalk by a Japanese astronaut took place aboard the shuttle Columbia. The heavy-lift Ariane 5 is on target to begin commercial operations in 1998, and the continual launch of communication satellites is bringing instant communications to all parts of the planet. Those few examples of the accomplishments of some of the space agencies around the world illustrate the unique mission that excites and inspires human thought on the planet. And it is that unique mission, the people who carry it out and the laboratories, research centres and launch facilities where the work is accomplished that can make a unique and significant contribution to the educational community.

I. EDUCATION AND TRAINING IN SPACE SCIENCE AND TECHNOLOGY

7. For spacefaring States, education and training in space science and technology consist of production and training of future scientists and engineers for sustainability, and the development of the discipline has been entrenched in the school curriculum from the elementary to the tertiary levels of education. At all levels, education is supported by audio-visual aids of high quality (slides, videotapes, CD-ROM etc). "Enrichment activities" for students, such as visits to planetariums, science fairs and conferences, motivate them to develop an interest in high technology in general and in space science and technology in particular. Many educational institutions in spacefaring States now place emphasis on the importance of an interdisciplinary approach to science and technology and socio-economic education. That approach promotes a strong educational base from elementary through university levels.

8. In developing countries, education and training in space science and technology, where they exist, are often limited in scope. They consist essentially in the demystifying and demythologizing of, and in learning how to apply, the new technologies introduced in this discipline. Some developing countries, such as Brazil, China and India, are spacefaring States that have made significant advances in space science and technology, and their educational curricula have been revolutionized by those advances. Other developing countries are participating

actively in space science and technology by contributing experimental payload and hardware, conducting relevant ground-based observations and analysing and interpreting satellite-borne data.

9. The new technologies impinge directly or indirectly on solar-powered devices, on transport and telephone networks, on rural education, on health-care delivery, on new ways of processing goods and on provision of services. Education and training in space science and technology can provide many developing countries with opportunities to modernize and pursue a more dynamic development. Developing countries can take advantage of the benefits of the new space-related technologies within their economic growth and development process.

II. CURRICULA FOR SPACE SCIENCE AND TECHNOLOGY EDUCATION

10. At any given point in the history of humankind, scientists and engineers possess an array of knowledge, skills and practices and a variety of instruments, all of which are built up over time. Over the last 40 years, there has been an accumulation of knowledge and of an enormous corpus of scientific literature on space science and technology. The transmission of that knowledge and information to students via education and training demands that a vibrant curriculum of studies be organized at all levels within the educational systems of different countries. It must be noted, however, that the condition of education (elementary, secondary and tertiary) varies significantly across countries, and across institutions within the same country. Those different conditions lead to differences in the space sciences and technology curricula in terms of course content and modes of presentation.

11. Education and training at the tertiary level, especially at the postgraduate level, often place emphasis on the new developments in space science and technology, the applications of new technologies and the acquisition, processing, interpretation and management of data. The training at the graduate level also requires motivation of students to apply the knowledge acquired in research projects. Students at that level are often of varying intellectual origins and are at different levels of preparedness to engage in a course of study in space science and technology. Remedial measures aimed at filling the gaps in background knowledge are therefore required to ensure that students benefit from the course. Diagnostic tests and exploratory lectures can be given to assess specific areas of inadequacies. What is expected of all the students is cognitive and linguistic capacities, ability for reflective thinking and a general background in science subjects. In programmes in space science and technology, there is always a gap between original ideas that guide the development of the curriculum and the translation of the curriculum into practical terms. That gap varies from country to country, depending on the availability of instructional materials necessary to translate ideas into practice.

12. Four major disciplines are often commonly identified in the education and training programmes of space science and technology at the postgraduate level.* They are briefly discussed below.

A. Remote sensing and Geographic Information Systems

13. A remote sensing applications programme is a particularly important component in space science and technology education. It stresses the fact that remotely sensed data provide an ideal view of the Earth for many studies that require synoptic or periodic observations, such as inventory, surveying and monitoring in agriculture, forestry, range management, geology, water resources and the urban environment. Remote sensing observations make use not only of visible light, but also of several other regions of the electromagnetic spectrum, such as the infrared, thermal and microwave regions. Different techniques may be required to handle

*For further details, see *Centres for Space Science and Technology Education: Education Curricula* (A/AC.105/649).

and analyse those different types of data. Much of the data is in digital form and can be processed using digital imaging and data analysis techniques to improve the visual appearance or to extract the required information.

14. Such a programme covers the technology of image acquisition, digital image processing, Geographic Information Systems (GIS), ground data collection and use, image interpretation and project planning and management. The programme also includes practical work and offers participants the opportunity to become proficient in the use of image processing and GIS software. Commonly, the first part of the programme is broadly based in order to give participants exposure to different techniques, instrumentation and types of data. A thorough background in the physical principles involved is provided. In the second part of the programme, participants explore different applications of remote sensing and specialize in a specific application to suit their own experience or needs.

B. Satellite communications and information technology

15. The satellite communications and information technology programme is suited to develop the skills of university educators, researchers, telecommunication professionals, government personnel and others in the field of satellite communications and its applications to broadcasting, telecommunications, health care, education, disaster management and mitigation, positioning and search and rescue operations. It is designed to assist in the preparation of satellite-based communications projects, policy definition, the establishment of communications systems and the integration of advances in communication technology in day-to-day activities. A major element of the programme consists in ways and means of developing and enhancing public awareness regarding the benefits of satellite-based communications technologies in the improvement of the quality of life.

C. Meteorological satellite applications and global climate change

16. The meteorological satellite applications programme stresses the fact that, while meteorological satellites have operated in space for over three decades, the majority of the scientific, professional and educational communities of the world are still unaware that observations from those satellites are freely accessible, and that they can be applied, directly or combined with other information, to benefit large segments of the population of a country. They can also help to resolve specific problems affecting those populations, especially where the saving of lives, the protection of property or the responsible management of natural resources may be involved.

17. Meteorological satellites have been operating almost continuously since the beginning of the space age. Their continuing presence in space for decades to come is virtually assured, because of the importance that society at large places on the observation and forecasting of weather phenomena. The spacecraft have been launched by various States specifically to meet the needs of professional government meteorologists in those States which are responsible for providing weather forecasts for civil and military interests. However, most weather-satellite-launching States have designed their satellites to operate in such a manner that anyone, anywhere on Earth, who is within radio receiving range of the satellites can acquire the data free and use it for any purpose. Thus, real-time, direct read-out observations from the satellites are being used as an educational or training resource within schools. Such observations can also be used as a tool for forest fire detection, or to support air, sea and land transportation, or agricultural and fishing interests, or for a wide range of other non-meteorological purposes.

18. The global access to meteorological satellite data, as known today, was an initiative of the World Meteorological Organization (WMO); it was conceived to help to ensure that knowledge of space sciences and technologies that evolved as a result of free access to meteorological satellite observations can, and will be, utilized by many more individuals, organizations and States, particularly developing countries. It does so by endowing a core group of specialists in different countries with the analytical skills and technical knowledge that will enable them to instigate and sustain a wide variety of indigenous programmes in which technology

supports scientific, economic, educational and humanitarian programmes that will enhance the quality of life for broad segments of the population.

D. Basic space science and atmospheric science

19. With the rapid degradation of the environment, it has become vital for all countries of the world to concentrate on a better understanding of atmospheric dynamics, including the interaction of the atmosphere with the land mass and oceans. Realizing the gravity of the situation, the United Nations Conference on Environment and Development, held at Rio de Janeiro, Brazil, from 3 to 14 June 1992, proposed as part of its Agenda 21, a series of measures for addressing environmental conservation. The developing countries have limited capacity to undertake research and development in the field of basic space science and atmospheric science. The programme does outline basic elements in that field which can be introduced into educational curricula at the postgraduate level.

20. Yet on another level, space technology has made tremendous strides and its impact has been felt in a broad variety of sectors, especially those relating to natural resources and environment, meteorology and communications. Since spacecraft operate in space and receive, as well as transmit, electromagnetic signals through space and the atmosphere, the development of space technology and consequently its applications can be greatly enhanced through a deeper understanding of basic space science and atmospheric science.*

E. Two examples

21. In all four disciplines (sections A to D above), specific emphasis has to be placed on computer systems for image processing and data analysis. A suggestion of topics organized in appropriate modules is provided in a document issued by the Office for Outer Space Affairs of the Secretariat, entitled "Centres for space science and technology education—education curricula" (A/AC.105/649). The document was prepared specifically for the regional centres for space science and technology education (affiliated to the United Nations); however, the curricula could serve as a guide for any graduate programme in any country in the various disciplines. An improvement to the programme is the addition of a new discipline on microsatellite technology.

22. The South African experience[1] has shown how a mix of traditional systems engineering, project management and technology management could be applied to develop space-related high-technology products at a tertiary institution. The inclusion of a microsatellite technology and perhaps nanosatellite programme in the curricula of space science and technology education in the four disciplines outlined above (A to D) will challenge students with an inclination for engineering to make contributions to space-related hardware development. In an age of "blackboxing" of instruments, such a programme will help to demystify some aspects of instrumentation used to collect and analyse data from space platforms.

III. SPACE SCIENCE AND TECHNOLOGY AND THE NON-SCIENTIFIC COMMUNITY

23. In a report by the Royal Society of London,[2] the importance of conveying scientific and technological concepts and thoughts to the general public was underscored. The committee noted that "Better public understanding of science could be a major element in promoting national prosperity, in raising the public and private decision-making efforts and in enriching the life of the individual. These are nationally important

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*For further details, see UNISPACE III background paper 6 on basic space science and microgravity research and their benefits (A/CONF.184/BP/6).

long-term aims and require sustained commitment if they are to be realized. Improving the public understanding of science is an investment in the future not a luxury to be indulged in if and when resources allow."

24. If there is a need to inform the public on scientific endeavours in general, there is a greater need to encourage public awareness in matters of space science and technology. Although the place of science in human advancement is well recognized by most of the general public, the useful spin-offs of space science and technology are not appreciated as such. It is even more difficult for the public to see the relationship between national prosperity and public understanding of space science and technology. The growing influence of space activities on technology and engineering, on health sciences and the medical profession, on education and on information and communication science is largely unknown to the wider public. To many people, space activities are only directed towards discovering intelligent life in outer space and finding out how weather systems move from one region of the Earth to another.

25. There is therefore an urgent need for an awareness campaign, through existing educational systems, to improve the public understanding of space activities. Such a campaign should produce useful input to public thinking, which will lead to improved decision-making by policy makers on science matters in general, and on space science and technology in particular. Public understanding of the benefits derived from space activities will facilitate release of public and private funds for such activities. More employment will be created and national prosperity will increase.

26. Education and training in space science and technology is therefore not complete without outreach components at the centres for space science and technology education that are being established in different regions of the world at the initiative of the United Nations. Popular summaries of recent space activities, summaries of spin-offs from space science and technology, histories of space launchings with details of success and failures supported by video and film presentations, as well as summaries of social impacts of space activities, are good materials for a purposeful outreach programme. In presenting space science and technology activities to the public in that form, there is a risk of making the activity simply one social activity among others because it has been dissociated from the knowledge and science on which its prominence rests. The risk is worth taking, however, since the section of the public that most needs to be educated, although highly placed in decision-making positions, may not have the science background necessary to appreciate any literature with scientific content. People in such decision-making positions need to be at least familiar with the end products of space science and technology.

IV. REGIONAL CENTRES FOR SPACE SCIENCE AND TECHNOLOGY EDUCATION (AFFILIATED TO THE UNITED NATIONS)

27. As the need to develop indigenous capacity became paramount, the General Assembly, in its resolution 45/72 of 11 December 1990, endorsed the recommendation of its Committee on the Peaceful Uses of Outer Space (COPUOS) that the United Nations should lead, with the active support of its specialized agencies and other international organizations, an international effort to establish regional centres for space science and technology education in existing national/regional educational institutions in the developing countries.

28. The host countries for the centres are: India (for Asia and the Pacific); Brazil and Mexico (for Latin America and the Caribbean); Morocco (for French-speaking countries in Africa); and Nigeria (for English-speaking countries in Africa). Seven central eastern and south-eastern European countries plan to establish a similar centre that will operate in a network mode. There is a plan to establish a similar centre in western Asia.

A. Work programme and model curricula

29. The activities at each centre will be undertaken in two major phases. Phase 1 will emphasize the development and enhancement of the knowledge and skills of university educators and research and applications scientists in both the physical and natural sciences as well as in analytical disciplines. Those activities will be accomplished through rigorous theory, research, applications and field exercises over a nine-month period as laid out in the curricula of the educational programme of each centre. Phase 2 will focus on ensuring that the participants make use of the skills and knowledge gained in phase 1 in their pilot projects.

30. The model curricula for the centres provide for a two- to three-month obligatory common curriculum for all participating scholars, and a six- to seven-month individual curriculum in: (i) remote sensing and geographical information systems; (ii) meteorological satellite applications; (iii) satellite communications and geopositioning systems; and (iv) space and atmospheric sciences. Thereafter, each participating scholar will carry out a 12-month project in his or her own country, where and when the knowledge gained at the centre is put into practical use.

31. In addition to providing opportunities for each scholar to gain the necessary knowledge, research experience and application skills in his or her chosen area of space science and technology, the programme of each centre also requires the scholars to complete an obligatory common assignment, which is the same for all participating scholars and is a prerequisite to the enrolment of each scholar in his or her chosen field of study. The common module will provide all the scholars with an overview of the observation of Earth and its environment from space and the use of data collected in such a process in atmospheric and terrestrial analysis. The obligatory programme will also expose the scholars to the physical principles of remote sensing, satellite orbital characteristics, operational sensors, satellite and ground-based communications, the impact of global positioning satellites on the integration and construction of remote sensing and GIS databases, and the demonstration of selected environmental applications.

32. Each centre aspires to be a highly reputable regional institution, which, as the needs arise, and as directed by its governing board, will grow into a network of specialty and internationally acclaimed affiliate nodes. The centres and their nodes will earn such a badge of honour through their contributions to the development of technologies that are appropriate to the solutions of the problems of their respective regions, and to the advancement of knowledge in an ever-expanding field. The model curricula for the centres provide the benchmark of the academic and performance level necessary to maintain the international standard and character needed for international recognition. Each centre will also foster continuing education programmes for its graduates and awareness programmes for policy and decision makers and the general public in its region.

B. Data management

33. An integral part of each of the centres for space science and technology education is a data management unit. Through such a unit, each centre will have direct linkages with existing relevant global data centres. Such linkages will enable the participating scholars to gain access to and utilize the data in the archives of various databases, particularly when undertaking projects and activities that could benefit from such an access.

C. Participating scholars

34. The possession by each applicant of a sound academic background, experience and an aptitude for engaging in the different activities of the centre cannot be overstressed. The richness of those attributes will have a positive impact on the performance of the applicant at the centre. To that end, each applicant (university educator, research or application scientists) should have obtained, from an internationally recognized university or institution, a minimum of a master's degree, relevant to his or her chosen field of study, followed by a

minimum of five years of relevant practical/working experience. An applicant with a Ph.D. degree, relevant to his or her chosen field of study and from an internationally recognized university or institution, should also have completed a minimum of three years of practical/working experience.

35. Of equal importance is the future of the participating scholars in their own countries on the completion of their studies at the centres. It should be emphasized that the overall mission of the centres is to assist participating countries in developing and enhancing the knowledge and skills of their citizens in relevant aspects of space science and technology in order that such individuals can effectively contribute to national development programmes. In order to ensure that appropriate and rewarding employment opportunities exist for those returning scholars, the sponsoring governments or institutions are obliged to: sponsor development-oriented activities that will gainfully utilize the newly acquired knowledge and skills of the returning scholars; and provide appropriate infrastructure and undertake the requisite preparations and plans for their career on a long-term basis. The sponsoring governments are also obliged to guarantee that a returning scholar would remain in such a position with commensurate and progressive remuneration and other entitlements for a minimum of three to five years.

D. Governing board

36. Because resolution 45/72 specifically limits the role of the United Nations to leading international efforts to establish the centres, it is apparent that once any of the centres is inaugurated, its governing board will assume all decision-making and policy formulation responsibilities for the centre.

37. In the context of the centres, a note is warranted on the purpose of the governing board. A governing board is the overall policy-making body of each centre; it oversees all aspects of the centre. It consists of member States (within the region where the centre is located) that have agreed, through their endorsement of the agreement establishing the centre, to the goals and objectives of the centre, and are committed to work, in cooperation with one another, for the well-being of the centre. A governing board, composed as described above, is necessary for each of the centres because member States and their own citizens are more familiar with their own peculiar needs, aspirations, capabilities and resources and are better equipped to find solutions to local problems that may surface. No part of the United Nations system, including the regional economic commissions, is equipped to address such an array of issues, particularly within the framework of the centres. And because such a centre has evolved through the efforts of the United Nations, the latter, including the relevant regional economic commissions, will serve the centre and its governing board in an advisory capacity.

V. APPRAISAL

38. Education in space science and technology can be introduced at the elementary school level and sustained through the secondary school to the tertiary institution levels. At all levels, space-related topics can be introduced into the general science curriculum. A course in science at those levels should be spread horizontally rather than vertically, placing greater emphasis on a secure foundation than on the levels attained. Such an approach provides the scope for introducing the basic elements of space science.

39. What should pupils learn about space science and technology at the elementary school level and how should the material be delivered? To answer those questions, suggested appropriate topics include popular astronomy, based on what can be seen by the naked eye, and the evidence for such phenomena as gravity. At those levels, pupils are unaware of the underlying theories and the materials should be presented more as story-telling than as a formal scientific presentation. Story-telling, fictional or factual, about space science and technology can be a very powerful early way of conveying notions about the subject.

40. At the high school (secondary school) level, the approach to introducing space science and technology should aim at helping students cultivate the ability to think in terms of science and accounting for what happens in terms of both observable as well as unseen events. Stories told at the elementary school level can be given concrete meaning at that level. The simulation of satellite orbits on personal computers and analysis of simple data from space-based instruments could also be introduced at this level.

41. At the tertiary level, students should be encouraged to develop reflective thinking in their approach to learning about space science and technology. Reflective thinking is the highest in the hierarchy of intellectual skills. It implies that given a problem, a student can analyse the problem, recognize the relevant data to use, recall all the concepts and principal facts relating to the solution of the problem, and, lastly, use all the facts to arrive successfully at the solution.

42. At postgraduate levels, education and training should be more formal. The present areas of education and training in space science and technology, namely, remote sensing, basic space science, satellite meteorology and satellite communication, need to be expanded to cover education and training in the development of microsatellites and nanosatellites. The expanded programme should include outreach programmes.

Notes

[1]A. Schoon Winker and G. W. Milne, "University research and development of a microsatellite", *Research and Development Management*, vol. 17, No. 1 (1997).

[2]Royal Society, *Report of Committee on the Public Understanding of Science* (London, September 1985).

Annex

SPACE SCIENCE AND TECHNOLOGY EDUCATION WITHIN THE SETTING OF SPACE AGENCIES

1. Education and training in space science and technology are integral programmes of the missions of many space organizations both in industrialized and developing countries. For example, such educational programmes exist in CNES, ESA, INPE, ISRO, NASA and NASDA. Each space agency has a unique mission, generally not performed by any other organizational entity within that country. For the purpose of the present background paper, educational programmes in space science and technology are illustrated by the educational elements within NASA.

A. Education

1. Mission, human resources and facilities

2. In the United States, the mission of NASA is as follows:

(a) To advance and communicate scientific knowledge and understanding of Earth, the solar system and the universe and to use the space environment for research;

(b) To explore, use and make possible the development of space for human enterprise;

(c) To conduct research in, develop, verify and transfer advanced aeronautics, space and related technologies.

3. The above-mentioned mission is carried out through four strategic enterprises (space science; Earth science; human exploration and development of space; and aeronautics and space transportation technology) that contribute to five United States national priorities, one of which is educational excellence. Such a unique mission inspires national pride, demonstrates real work applications of the traditional disciplines of science, mathematics, engineering and technology, and generates new knowledge for intellectual consumption.

4. The mission is carried out by people employed by the space agency, institutions of higher education and the private sector. Together, this very talented, highly educated pool of people represent an investment in human capital, many of whom are committed to returning to the educational community knowledge from which they have, as individuals, benefited. Moreover, unique facilities are required by each space agency to carry out its mission. It is the unique national assets, mission, human resources and facilities that provide a venue through which elements of the educational community can learn about and experience the knowledge derived from the mission of the space agency.

5. What is the relationship between those unique assets and the educational community? The NASA strategic Plan 1998, on educational excellence, states: "We involve the education community in our endeavors to inspire America' s students, create learning opportunities and enlighten inquisitive minds."* The one guiding word that drives the NASA education programme is "involve". How NASA involves the educational community in its mission is dependent upon the educational level and both its needs and capabilities.

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*See NASA Policy Directive 1000.1, page 9.

2. Involving the elementary and secondary education community (kindergarten through grade 12)

6. The United States elementary and secondary education community is large and diverse. Approximately 51.7 million students are enrolled, taught by approximately 3.1 million teachers, in 14,772 school districts in 50 states and the District of Columbia (Washington, D.C.). Funded at a total of $287.5 billion, over 93 per cent of the amount is provided by the state or locality. Fundamentally, education in the United States is controlled by the individual states and localities, not by the federal Government.

7. Because of such diversity, the NASA education programme at the elementary and secondary level seeks to translate its mission into reality to meet the educational needs of the 50 states. And because of its mission, the primary focus of NASA at the elementary and secondary level is in support of the disciplines of mathematics, science and technology education. Therefore, the programmes are guided by state curriculum standards and frameworks.

8. The NASA education programme (K-12) emanates from the 10 NASA field centres, each of which is assigned specific states, so that in total, all 50 states and the District of Columbia are involved. In applying the knowledge learned from the NASA mission to meet the agenda of education throughout the country, NASA involves the K-12 educational community through five implementation approaches: (a) student support programmes; (b) teacher preparation (pre-service) and enhancement (in-service) programmes; (c) curriculum support and dissemination; (d) educational technology; and (e) support of systemic educational change in a state or locality.

9. In fiscal year 1997, NASA pre-college education programmes involved over 1 million students and 100,000 teachers in all 50 states and the District of Columbia. Although by no means comprehensive, some of the NASA K-12 education activities are described below.

10. *Student support.* Responding to the national need to encourage more under-represented groups to pursue science, mathematics and engineering occupations, NASA annually supports approximately 500 high-school students (grades 10 and 11) to undertake eight-week research apprenticeships at a NASA field centre or university from June to August each year. Each apprentice works with a scientist or engineer to assist in his or her research, thus gaining valuable technical experience. Evaluation results indicate that students participating in the programme enrol as college science and engineering majors in a significantly greater percentage than the general student population.

11. Another example of the K-12 programme targets students in grades six to eight. The programme seeks to provide students and their teachers access to unique NASA instrumentation, data and Earth observations. Using an electronic still camera on board the space shuttle, students use the Internet to send coordinates for an image to the programme operations centre. After review and verifications, coordinates are sent to mission control, which forwards the command to the orbiting space shuttle. On board, a computer directs an internally mounted electronic still camera to capture the image, which is downloaded to mission control and sent back to the student via the Internet. Such Earth observations are integrated into the science and mathematics curriculum by the teacher.

12. *Curriculum support and dissemination.* As previously stated, what students are taught and subsequently learn is determined by local communities and states. Therefore, NASA seeks to understand, in a broad sense, common curricula topics or standards, and engages outside education experts to develop curriculum materials for the life sciences, physical sciences, Earth system science, astronomy and planetology, and mathematics. Those materials are derived from the mission activities conducted through the four NASA enterprises. Materials developed are in print, CD-ROM, Internet-based, or videotape formats. All NASA educational materials are

distributed through either an education resource centre (located in each state, usually at a university, museum or similar education venue) or through the Internet via the NASA education home page.

13. *Teacher enhancement.* Support materials developed by NASA serve as the content for most teacher enhancement workshops done by NASA. Such workshops, conducted by previous science, mathematics and technology teachers employed under a NASA contract, are provided to teachers in their schools during the academic term and at NASA field centres during the summer. The NASA Education Workshop, for example, is a programme operated cooperatively with the National Science Teachers Association, the National Council of Teachers of Mathematics, and the International Technology Educator's Association. The programme, announced nationally, is highly competitive and provides, for 250 K-12 mathematics, science and technology teachers, a two-week in-service experience at a NASA centre. Teachers receive technical briefings on missions and projects, in-depth tours of research and development and operational facilities, and technical training sessions on accessing NASA educational electronic materials and information sources. Significant workshop time is then devoted to applying those experiences to meet the needs of the curriculum or programme of study of the individual teacher.

14. *Education technology.* Perhaps the most significant area of growth in the NASA education programme is the better understanding and use of educational technology in the learning process. An educational technology research and development (R&D) centre has been established at a university to develop state-of-the-art electronic instructional materials and Web-based instruction, and to train teachers in their use. Distance learning programmes, originating from NASA centres, are targeted at teachers on a state, regional and national basis, many times in partnership with United States public television organizations.

15. *Support of systemic change.* As the United States continues to reform science, mathematics and technology instruction in its K-12 schools, NASA has placed emphasis on coordinating the total NASA assets in a given state in order to assist in meeting the educational reform agenda of the state concerned. Largely accomplished by establishing a variety of partnerships, NASA seeks to convene meetings of NASA principal investigators, NASA-trained teachers and commercial contractors with the state educational leadership to determine how those assets may best be utilized within the state.

3. GLOBE programme

16. An opportunity exists for space agencies throughout the world to jointly participate in a programme that integrates numerous approaches as described above. GLOBE is a hands-on, school-based (K-12) international environmental science and education programme. Students in almost 5,000 schools in the United States and over 60 other countries are taking important environmental measurements to produce a global data set of long duration. GLOBE measurements, which have been selected by the world science community, span the environmental study areas of climate, within the field of atmospheric science, and hydrology, soils and land cover, within the field of biology. Students report their data using classroom computers and the World Wide Web and the Internet. The data are archived and also turned into vivid contour maps that are returned to GLOBE schools for use in the classroom.

17. Students in GLOBE schools around the world are performing authentic tasks. The data which they collect are used by scientists in real research to understand the dynamics of the environment of Earth. They are also used by the students themselves to study their local environments and to do research projects with other schools around the world, with electronic mail as their communications mechanism. Such collaboration is enhancing environmental awareness, increasing scientific understanding of Earth and supporting improved student achievement in mathematics and science. At the same time, it is affording students around the world the opportunity to interact meaningfully with one another and thus to glimpses of other cultures.

4. Involving the higher education community

18. The United States higher education system is composed of 14.4 million students and approximately 900,000 faculty members. Funding for higher education totals approximately $192 billion annually, approximately 88 per cent of which is derived from sources other than the Federal Government.

19. Since its beginning in 1958, NASA has involved the higher education community as a significant intellectual resource in carrying out its strategy and missions. In fiscal year 1996, NASA funded 4,860 research grants and contracts at 417 institutions of higher education, totalling approximately $749 million. Research topics carried out in universities range from astronomy and physics, biological and medical sciences, atmospheric science and oceanography, to aeronautical engineering and materials science.

20. Though by far the largest, research and development actions carried out in higher education institutions represent only one of four implementation approaches used to involve the higher education community in the NASA mission. Additional approaches include student support, faculty enhancement and curriculum support.

21. In fiscal year 1997, NASA higher education programmes involved over 50,000 undergraduate and graduate students and 36,000 community college, college and university faculty members in all 50 states and the District of Columbia. While not comprehensive, some of the NASA higher education programmes are outlined below.

22. *Student support.* Each year NASA supports approximately 400 graduate students seeking to obtain a master's or doctoral degree in a discipline of interest to NASA. That national, competitive programme provides selected students and their professors with a fellowship of $22,000 to conduct research on a topic of interest to the space agency. Students are supported for a three-year period and perform the research in collaboration with a NASA principal investigator.

23. *Curriculum support.* Sometimes a new NASA mission dictates a new type of trained professional to carry out the mission. When Mission to Planet Earth became an approved programme, mission scientists realized that a new type of university graduate would be needed in the future, one who could work towards an understanding of the total Earth as an interrelated system and of the effects of natural and human-induced changes on the global environment. To address that need, the Earth systems science education programme was developed to provide universities with financial support to change undergraduate curricula to support Earth systems science. Approximately 30 universities are currently participating.

24. *Faculty enhancement.* In an effort designed to give new faculty members and others access to and understanding of NASA research needs, each year approximately 300 college and university faculty members are chosen nationally to conduct research at a NASA centre, renewable for one year. Approximately 90 per cent of the 10-week fellowship is devoted to research and 10 per cent to developmental activities. Approximately 40 per cent of the participants in the fellowship programme subsequently receive mainstream NASA R&D funding.

25. *Research and development.* As stated previously, the majority of NASA efforts in higher education are individual R&D grants and contracts. However, there are a few specific programmes that assist in developing research infrastructure and capability. For example, one such programme, the NASA Experimental Programme to Stimulate Competitive Research, provides, on a competitive basis, a $5 million grant to a state to develop a research capability in an area of interest to NASA. States eligible to participate are those that traditionally have not been successful in obtaining significant Federal R&D funding. NASA currently funds 10 such states.

B. Training and development

1. Background

26. To better understand the NASA approach to training and development, some background information is necessary. NASA strongly emphasizes its human resources, giving special priority to recruiting, developing and retaining a high-quality and diverse workforce. Having a capable, highly skilled workforce is critical to NASA success in accomplishing its mission. Currently, as a consequence of budget reductions, the ability of NASA to hire new employees has been and is expected to continue to be rigidly constrained. That in essence means that the achievement of NASA mission results will largely come from the contributions and efforts of the current workforce. Providing the training and development experiences to prepare the current workforce to meet the needs of today and tomorrow is vital.

27. It is also important to understand where organizational responsibility for training and development resides in NASA. Each NASA centre has a training and development office exercising primary responsibility for supporting the training and development needs of the employees and organizations of that centre, as prescribed in NASA policy. Each centre has a specific training budget allocated for that purpose. Since the centres have uniquely defined roles and responsibilities with specifically assigned missions, including designations as centres of excellence, their training needs are different. For instance, Ames Research Center (ARC) supports the Space Science Enterprise in Astrobiology and is a centre of excellence for information technology. ARC has determined the appropriate skill mix that it requires to accomplish those assignments, and its training and development function supports the needs of the ARC workforce. Stennis Space Center, a centre of excellence for rocket propulsion testing, has an entirely different skill mix and different training and development priorities to address.

28. An agency-wide training and development function overlays and supports the different centre training and development functions. At the agency level, two major areas are supported: executive and management training and programme and project management training. Agency-sponsored programmes bring together participants from across the agency to expose them to common approaches and the shared experiences of participants from other centres.

2. Strategic approach to training and development

29. As previously mentioned, NASA utilizes a skill mix assessment process to determine both the current and projected mix of workforce skills required at each NASA installation to achieve desired results. In some cases, to achieve the desired skill mix, personnel relocations are used, or minimal outside hiring occurs. In most cases, training and development is used to address the workforce skill requirements.

30. It is important to ensure that the training and development needs and priorities are aligned with the overall plans, goals and objectives of NASA. The primary objective of the NASA training and development function is to ensure that employees and organizations have the capabilities needed to accomplish NASA missions. That means building a skilled and proficient workforce. Within NASA, required skill sets are vast and diverse, involving scientific, professional, technical and management proficiencies. For example, the Aeronautics and Space Transportation Enterprise has three major technology goals supported by 10 enabling technology objectives. Among the many required technical proficiencies that must be supported are airframe design, aviation systems, flight dynamics and aeropropulsion. To achieve long-range goals, revolutionary technology leaps are anticipated in subsonic transport and aviation safety. It is imperative that NASA investment decisions be aligned to provide the training and development experiences required to adequately prepare the workforce to accomplish those objectives. In fact, within NASA, mere technical proficiency is clearly insufficient. To meet the aggressive goals of the future, NASA must support and develop cutting-edge technical proficiencies.

31. NASA also uses, wherever possible, a competency approach to human resource management and development. Competencies are identified areas of emphasis which describe an ability or a characteristic that has been deemed essential or critical to job success. For example, senior NASA executives should be competent in leading change, leading people, achieving results, exercising business acumen and building coalitions. To present another example, a manager of large and complex projects should be competent in participating in international partnering arrangements, systems engineering design and presenting information to political leaders and external stakeholders. Determination of job competencies should be based on a sound research and validation programme. Once validated, NASA employs competency assessment and feedback instruments in its training programmes to provide a way to gauge participant competency levels.

3. Four cornerstones

32. The NASA strategic approach to training and development has focused on four components or cornerstones, which support both employee and organization needs. The first two components centre around capability. Capability assumes that the requisite skills (or proficiencies) and competencies are suitably developed and available for application to the specific job. More than half of the NASA workforce is composed of engineers and scientists. Organizationally, NASA is structured around programmes and projects. It is therefore expected that most of the emphasis to date has been on identifying and developing technical skills and competencies, particularly for programme and project managers. The efforts undertaken are known as the Programme/Project Management Initiative (PPMI). The NASA PPMI programme consists of a curriculum of core and skill courses, a professional developmental programme, project management tools and resources, and consultant support to intact project teams. PPMI was established to revitalize the NASA focus on project management competencies. The curriculum itself consists of almost 25 different courses. Additional work has also gone into developing career development maps for future aspiring project managers and other interested personnel that outline recommended formal and informal training and developmental experiences beneficial for growth and advancement. The initiative is called the Project Management Development Process (PMDP). The PMDP process identifies work experiences and training for development of programme and project management knowledge and skills. It is a tool and guide for professional and career planning to prepare for future assignments.

33. Executive and management development is another key priority in skill and competency enhancement. Skills and competencies for senior and mid-level managers and team leaders have been researched and validated. Mid-level managerial competencies, for example, include establishing plans and priorities, monitoring work progress, and resolving work unit conflicts, to name just a few. NASA training programmes and development experiences have been designed to provide learning opportunities to improve skill and competency in those areas. A focus on capability (skills and competencies) alone is not sufficient to achieve mission success. Mission support training is the third necessary component of the NASA training and development initiative. Mission support training involves training in specialty areas and subjects bearing on successful mission accomplishment. They may be subject areas like safety, environmental management, security, or some type of legislatively mandated training. An engine test engineer, for example, in addition to being skilled and competent in propulsion testing techniques and procedures, needs to know, understand and apply other knowledge, skills and abilities, which might involve, for example, safety procedures and practices and environmental control procedures. The mission support component provides NASA employees with other essential training and development experiences required to perform the core function smoothly, properly, safely, efficiently and effectively.

34. Lastly, and perhaps just as importantly, the fourth major component of training and development is professional development. This area addresses individual needs for growth and development. Every individual, although skilled, competent and knowledgeable in performing current responsibilities, has an expectation to grow and learn, and strives to solve new problems and achieve new goals. NASA strongly values individual and

professional development, and provides a wide range of avenues to employees to develop their full potential and prepare them for new and different responsibilities.

4. Training and development experiences

35. Both formal and informal training and development methodologies are considered to be essential ingredients in an effective workforce development programme. On-the-job training through selected work experiences constitutes the primary approach for employee development. That may include both NASA and non-NASA work experiences and rotational assignments within the home centre of an employee or to another centre, headquarters, another federal agency or outside the Government entirely. Formal training and educational experiences are used to complement the work experience. Much learning also takes place at technical symposia and conferences. Both undergraduate and graduate tuition assistance programmes are available to NASA employees. Each employee is encouraged to develop an individual development plan in concert with his or her supervisor or manager in order to frame, plan and track his or her individual development needs. The plan should also be aligned with the needs of the organization. The use of mentors, while generally optional, is strongly encouraged. The sound advice of an experienced senior professional can significantly improve the developmental planning process for an employee.

5. Technology and automation

36. Technology and automation advances have brought about new support systems that significantly expand the resources available to employees in performing work assignments. In essence, new learning networks are being created to support job performance. Those networks provide tools, job aides, best practices and other electronic resources, in addition to just-in-time training. The materials are delivered to the employee at his or her workstation, and are available on-line as necessary. For instance, a quality engineer developing calibration requirements for spacecraft design will be able to access NASA calibration policy documents, lexicons, resources, references and World Wide Web links to other organizations such as, in the present example, the repository for national reference standards, the National Institute of Standards and Technology.

37. Other techniques being employed in NASA include the use of groupware and computer conferencing. Groupware is a computer-based technology that supports group and team interaction at the same time and in different places through a networked workstation arrangement. Computer conferencing is being used to establish electronic training classrooms, permitting real-time interaction between trainer and student. The use of distance learning and other alternate delivery techniques and movement to automated tools and resources is expanding rapidly.

C. Training and technology transfer in developing countries

38. Training in the concepts and techniques of remote sensing, geographic information systems, image processing, and geospatial data analysis should be an indispensable part of current technology transfer efforts with developing countries. Effective decision-making regarding environmental issues requires a knowledge of, and facility with, those technologies. However, effective implementation of the technologies also requires that technicians and spatial data analysts understand the context of the task and work with others who are knowledgeable about the environmental disciplines and concepts of geospatial data analysis. Otherwise, the software and systems will become simply a tool for visualization of geospatial data, with little or no meaningful analysis involved.

39. The Earth Resources Observation System (EROS) Data Center of the United States Geological Survey (USGS) has applied the philosophy outlined above in providing training in remote sensing, GIS and image processing in many regions of Africa since 1987. Most USGS/EROS Data Center projects in Africa involve

some aspect of training, whether regarding hardware, software and network installation and maintenance, or training in analysis concepts and techniques. Training has been provided in the form of short-term (two to three weeks) and long-term (over one year) in-country courses, formal and informal training and workshops at the EROS Data Center, and coordination of formal training at various institutions of higher learning in the United States.

40. In recent years, USGS has provided training as an important part of two major cooperative projects supported by the United States Agency for International Development (USAID): Sustainable Approaches to Viable Environmental Management, in Madagascar; and the Regional Centre for Training and Applications in Agrometeorology and Operational Hydrology (AGRHYMET), in Niger. Through those efforts, institutions such as the National Association for the Management of Protected Areas and the National Institute of Geography and Hydrography in Madagascar and the AGRHYMET Centre in Niger have been strengthened in their capacity to integrate multi-source data and to carry out multisectoral geospatial analyses.

41. USGS also provides training to help scientists and information specialists in other countries to make data and information from their countries available through the Internet. The EROS Data Center recently presented the Inter-American Geospatial Data Network (IGDN) Clearinghouse Workshop to a group of scientists and database managers representing government agencies and academic institutions that provide and use geospatial data for the Caribbean region and North, South and Central America. The primary objective of the Workshop was to train participants in the use of Internet-related tools and metadata standards compliant with those of the United States Federal Geographic Data Committee to enable them to establish IGDN nodes in their home countries. The IGDN project promotes the implementation of Internet capabilities throughout the western hemisphere for electronic access to information describing the existence and availability of geospatial data. It is a cooperative project of USAID and USGS and is being supported by the Pan American Institute of Geography and History.